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Evaluation of Biogas Production from the Digestion of Swine Dung, Plantain Peel and Fluted Pumpkin Stem

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Abstract— *This study centered on biogas production from locally available animal and kitchen wastes: swine dung (SD), plantain peel (PP) and fluted pumpkin stem (PS) using five 32-Litres metallic prototype digesters. The anaerobic digestion was in the ratio of 3:1 of water to waste for all the samples as follows: Sample A was 100%SD, Sample B; 100% PP, Sample C; 100% PS, Sample D; 50%SD+50%PP and Sample E; 40% SD+30% PP+30% PS. The retention time was 30 days and parameters like pH, pressure, daily biogas production, ambient and slurry temperatures alongside the physico-chemical properties of wastes were monitored. The cumulative gas production yield was 11.5L, 35.1L, 39.5L, 46.9L, 59.3L for Sample A, Sample B, Sample C, Sample D and Sample E respectively. The flammable time was 15th, 5th, 25th, 26th, 2nd day for sample A, sample B, sample C, sample D and sample E respectively. The result revealed that the blend of the 3 substrates i.e. sample E: 40% SD+30% PP+30% PS gave the highest yield of biogas and flamed earlier than the other samples while sample A: 100%SD had the lowest yield of biogas. The results also showed that the sample that had the highest composition of methane in the biogas produced was Sample D: 50%SD+50%PP with 85.6989% while the lowest composition of methane was found in Sample C to be 79.0996%. The TS, TVS, BOD and VS were seen to be consistently reducing showing the level of waste treatment achieved during the digestion period of 30 days.*

Keywords— Swine Dung, Plantain Peel, Fluted Pumpkin Stem, Daily Biogas Production, and Evaluation.

Abbreviations: TS=Total Solid, TVS=Total Volatile Solid, VS=Volatile Solid, BOD=Biochemical Oxygen Demand, TVC= Total Viable Count

I. INTRODUCTION

It is no doubt that one of the major challenges to human and environmental health, and economic development of any society especially in developing countries, is the continuously increasing production and inefficient functional Environmental Waste (organic wastes) Management Policies. Plants and animal wastes are integral part of biological existence in that the rate and volume of organic waste production is bound to exist and of course to increase with the increasing world population. It is very obvious that due to the current economic disposition of the country that the campaign for continued and extensive agricultural production is the gear to the nation's economic wheels. In other words, there will be increased agricultural inputs and of course a corresponding increase of output in both subsistence and commercial quantities hence, increasing the waste potential of the agricultural sector through the stages of production, processing, transportation, consumption and disposal. Subsequently, generation of wastes cannot be totally eliminated neither can waste recycling be achieved completely, thus the need for a more cost effective and efficient process to optimally reduce the effects of these wastes while providing a sustainable energy and eco-rejuvenation through anaerobic digestion.

Literature contains substantial biogas production from different wastes in the locality. Nwankwo, 2014 did a research on the digestion of plantain peel (PP) and the codigestion of plantain peel with swine droppings (PP-SD) to observe the biogas production ability in a 50litres metal prototype biodigester. The waste (PP and PP-SD) were subjected to anaerobic digestion for a period of 44days. The cumulative biogas yield for the plantain peels alone (PP) was 80.10dm^3 while that of plantain peels mixed with swine droppings (PP-SD) was 163.30m^3. The PP-A commenced flammable gas production on the 2nd day while, PP-SD

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commenced flammable gas production on the 30th day. The PP-SD had the highest cumulative gas yield though with a slow onset of gas flammability. The overall result indicates that the low gas yield of PP could be significantly enhanced by blending it with swine droppings. Ezekoye, 2013 carried out a research on Plantain/almond leaves and pig dung used as substrates in anaerobic bio digester for producing biogas by batch operation method within the mesophilic temperature range of 20.0 to 31.0°C. The study was carried out to compare biogas production potential from plantain/almond leaves and pig dung wastes. The cumulative biogas produced from the plantain/almond leaves was 220.5L while the cumulative biogas from the pig dung was 882.5L. The methane component of gas from pig dung was 70.2% while that for plantain/almond leaves with algae was 72.7%. The biogas from the almond/plantain leaves became combustible on sixteenth day while the biogas from the pig dung was combustible on fourteenth day. Results showed that pig dung produced more biogas than the almond/plantain leaves within the same period.Ofili et al., 2010 researched on the quantity of biogas yield from anaerobic digestion of rabbit waste and swine dung. The same volume of digester was used in this experiment to accurately compare the volume of the biogas yield. The maximum volume of biogas produced from the 45 litresdigester used was 8.2 litres and 6.8 litres respectively for swine dung and rabbit waste. It was observed that the biogas production from swine dung was greater than that of rabbit waste. These studies focused on anaerobic digestion of one substrate and or co-digestion of only two subtrates. Co- digestion was not extended to more than two wastes, hence the objective of this study. The study also looked into the mix of the co-digested wastes for maximum biogas production.

II. MATERIALS AND METHODS

Swine dung was collected from the Animal Farm, Faculty of Veterinary Medicine, University of Nigeria, Nsukka. Plantain Peels and Fluted Pumpkin Stem were collected from various restaurants in the University of Nigeria, Nsukka. Five metallic model biodigesters (figure 1), utilized for the study were each of 32.0L working volume (fabricated locally at the National Centre for Energy Research and development, University of Nigeria, Nsukka). The schematic of the biodigester is shown in figure 2. Materials such as top loading balance (Camry Emperors Capacity 50kg/110 Ibs), plastic water troughs, graduated transparent plastic buckets for measuring daily gas production, pHep pocket-sized pH meter (Hanna Instruments), thermometers, pressure gauge, thermoplastic hose pipes, metallic beehive stand, biogas burner fabricated locally for checking gas flammability, were used.

Fig.1: Five 32-L Bio digesters Used

SAMPLE PREPARATION

The plantain peels were chopped into small pieces and allowed to ferment for four days while the pumpkin stems were also chopped into small pieces and soaked in water for 24hrs. The aim of the chopping into smaller pieces and the soaking was to soften the substrates so that micro-organisms involved during the anaerobic digestion (anaerobic microbes) will have access to them easily for quick production of biogas and partial degradation since they are known to be better decomposers of cellulose (Fulford, 1998)

In carrying out this research, five samples were used. The digesters with only one sample served as the control while the digesters with more than one sample served as the experiment. The contents of the digesters were as follows:

- **Sample A**: Swine dung control i.e. 100% swine dung
- **Sample B**: Plantain peel control i.e. 100% plantain peel
- **Sample C**: Fluted pumpkin stem control i.e. 100% fluted pumpkin stem
- **Sample D**: Swine dung and Plantain Peel i.e. 50% swine dung and 50% plantain peel
- **Sample E**: Swine dung, plantain peel, and fluted pumpkin stem i.e. 40% swine dung, 30% plantain peel and 30% fluted pumpkin stem

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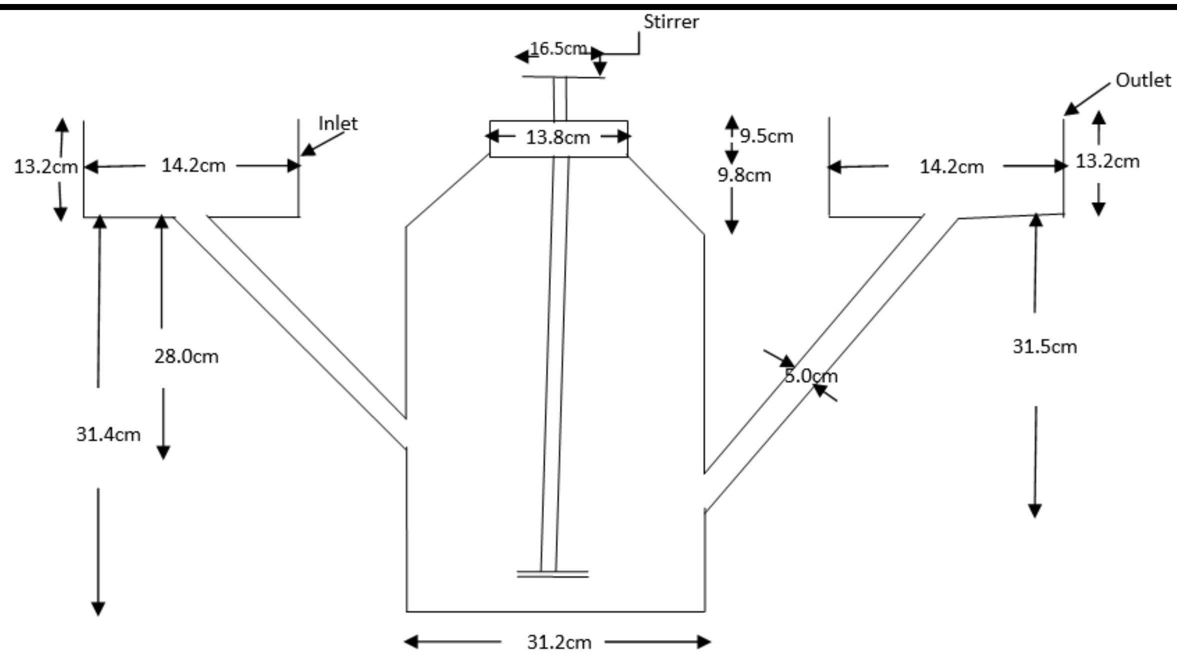

Fig.2: Schematic Diagram of the Biodigester

Fig.3: Chopped Fluted Pumpkin Stem

Fig.4: Chopped Plantain Peels

Fig.5: Bag containing Swine Dung

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III. EXPERIMENTAL SET-UP

Each of the digesters was charged to 75% of its 32litres capacity. Therefore, a measurement of the amount of a particular specimen needed was taken in relation to the equivalent of 75%. This was done so that there would be vacuum for the production of biogas.

Capacity of the digester = 32litres which is equivalent to 32kilograms

Charge percentage for each digester = 75/100 * 32kg = 24kg

SAMPLE A: 6kg of swine dung was weighed and charged with 18kg of water in the ratio of 3:1 of waste to water. The initial pH was 6.7.

SAMPLE B: 6kg of plantain peel was weighed and charged with 18kg of water in the ratio of 3:1 of waste to water. The initial pH was 4.8.

SAMPLE C: The fluted pumpkin stem was sieved using the field sieve to prevent water from interfering with the measurement (weight). 6kg of the fluted pumpkin stem was weighed and charged with 18kg of water in the ratio of 3:1 of waste to water. The initial pH was 6.6.

SAMPLE D: 3kg of swine dung and 3kg of plantain peel was weighed and charged with 18kg of water in the ratio of 3:1 of waste to water. The initial pH was 5.5.

SAMPLE E: 2.4kg of swine dung + 1.8kg of plantain peel + 1.8kg of fluted pumpkin stem was weighed and charged with 18kg of water in the ratio of 3:1 of waste to water. The initial pH was 7.0.

Physicochemical and Microbial Analyses

The physical and chemical compositions of the undigested wastes were determined before the digestion. Ash, moisture, crude fibre, crude nitrogen, crude fat, crude protein, BOD, contents were carried out using AOAC method of 2005. Total Solidsand Volatile Solids were determined using method adopted by Meynell (1982). Phosphorus, potassium, energy contents were determined using methods described in Pearson (1976). TVC was determined using methods described by Ochei and Kolhatkar (2000). Carbon content was determined using methods described by Schumacher (2002). The population of the microbes in each of the treatment cases was determined at different times (at charging, flammable, peak of production and end of digestion), during the period of study to monitor the growth of the microbes at the various stages. Temperature, pH and pressure were also monitored.

Gas Analysis

The flammable gas compositions from the five digesters were analyzed using BACHARACH (PCA2) Gas Analyzer, made in United States.

Data Analysis

The data obtained for the volume of gas production from each of the systems were subjected to statistical analysis using SPSS ver.20 and Microsoft Excel XP 2007.

IV. RESULTS AND DISCUSSION

Table 1 shows the physicochemical properties of undigested wastes.

Table.1: Table of the physicochemical properties on the charging day (Day 0)

PARAMETERS	100% SD	100% PP	100% PS	50% SD+50% PP	40% SD+30% PP +30% PS
Moisture Content(%)	96.15	88.46	84.62	91.38	90.74
Ash Content (%)	0.40	4.80	7.10	2.00	2.50
Crude Fibre (%)	0.80	3.69	5.29	2.20	3.00
Crude Fat (%)	0.39	0.87	1.26	0.64	0.78
Crude Protein (%)	2.10	1.05	0.96	1.49	1.40
Crude Nitrogen (%)	0.3357	0.1678	0.1540	0.2378	0.2238
Carbon Content (%)	2.87	3.91	4.63	3.43	3.83
Phosphorus (%)	0.6	2.1	1.4	1.3	1.8
Potassium (mm/l)	1.1	1.7	1.2	1.5	1.6
Volatile Solids (%)	2.77	10.36	12.68	7.37	8.60
Total Solids (%)	2.77	12.03	15.11	8.00	9.50
B.O.D(mg/l)	73.6	43.2	40.0	57.6	59.2
Total Viable Count (cfu/ml)	$58.33X10^5$	$41.67X10^5$	$33.33X10^5$	$45.83X10^5$	$50.00X10^5$
Carbon-Nitrogen Ratio	8.5	23.3	30.1	14.4	17.1

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Table 2 shows the gas compositions for the various substrates.

Table.2: Table of gas composition of the flammable gas from experiment

Sample Substrates	Retention Time(Day)	Cumulative Volume of Biogas(L)	Flammable Time(Day)	Component of Biogas (%)			
				CO_2 (%)	CO (%)	CH_4 (%)	Other components
SD (100%)	30	11.5	15	23.5	0.4922	73.0078	3
PP (100%)	30	35.1	5	17.0	0.0373	79.9627	3
PS (100%)	30	39.5	25	17.9	0.0004	79.0996	3
SD (50%)+PP (50%)	30	46.9	26	11.3	0.0011	85.6989	3
SD(40%)+PP(30%)+PS(30%)	30	59.3	2	17.8	0.0039	79.1961	3

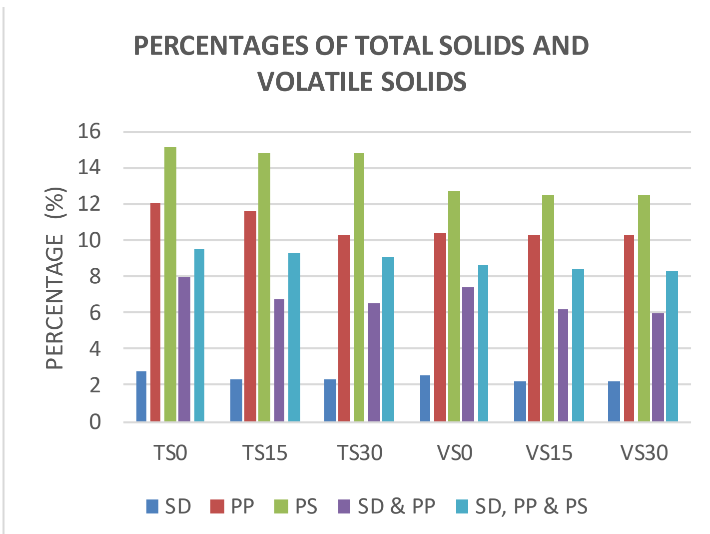

Fig.6: Chart of TS and VS of digested substrates for days 0, 15 and 30

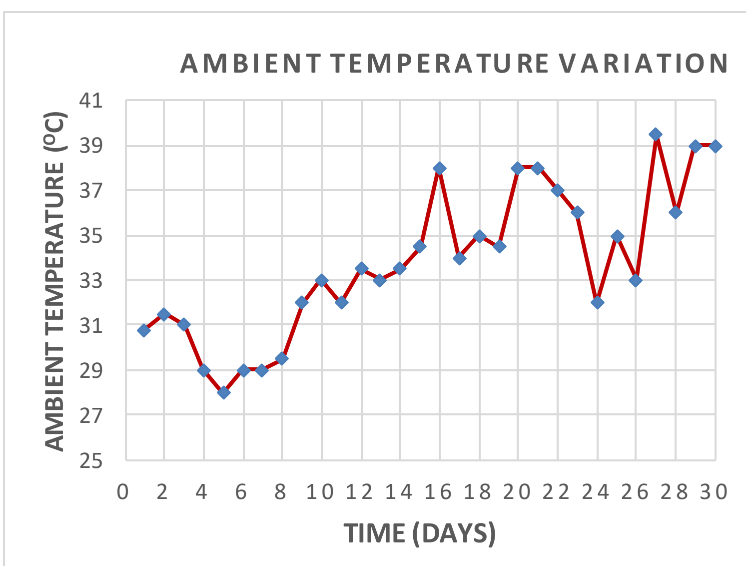

Fig.7: Graph of Ambient Temperature (°C) against Retention Time (Days)

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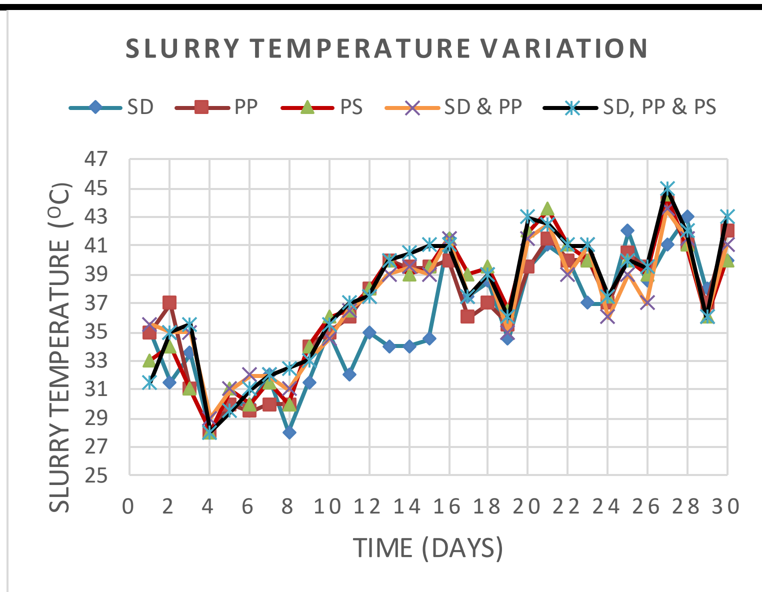

Fig.8: Graph of Slurry Temperature (°C) against Retention Time (Days)

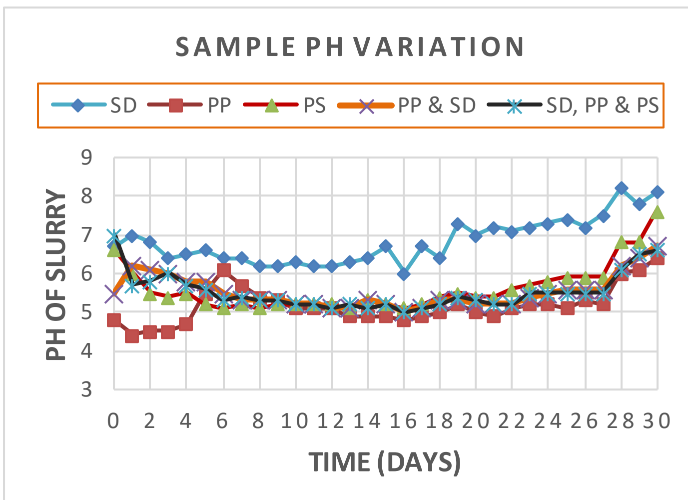

Fig.9: Graph of pH of Slurry (°C) against Retention Time (Days)

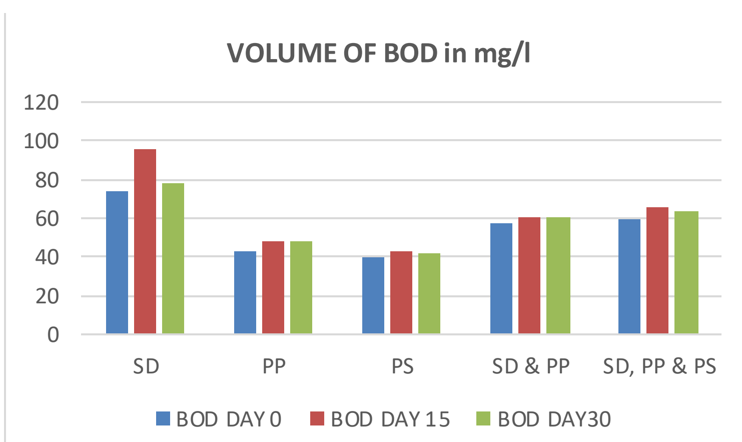

Fig.10: Graph of Biochemical Oxygen Demand at various times

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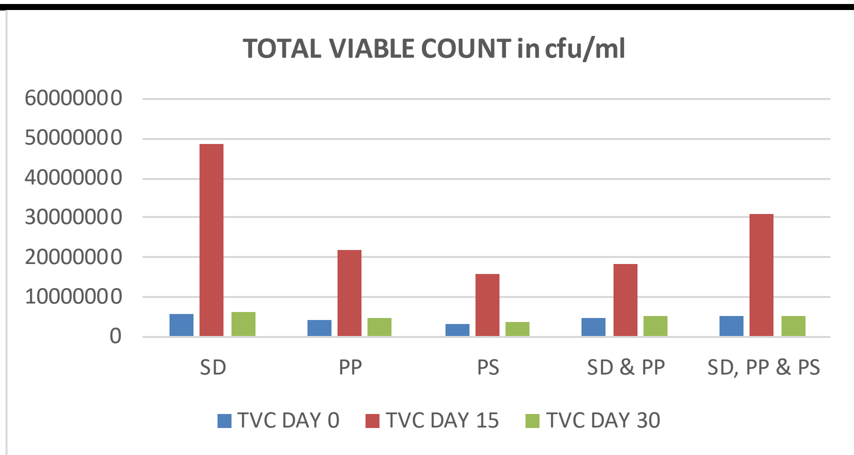

Fig.11: Chart showing the TVC of samples for days 0, 15 and 30

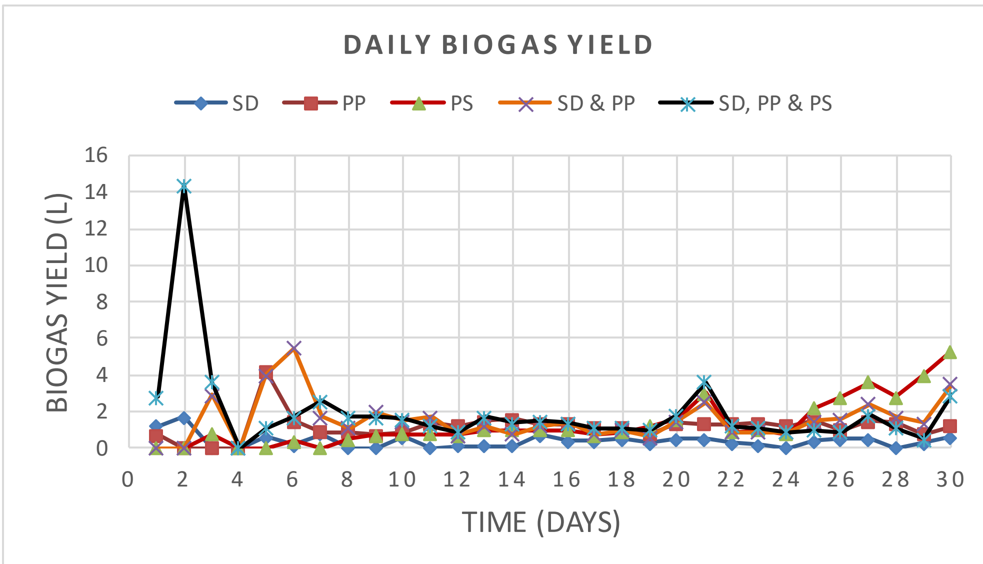

Fig.12: Graph of Daily Biogas Yield against Retention Time

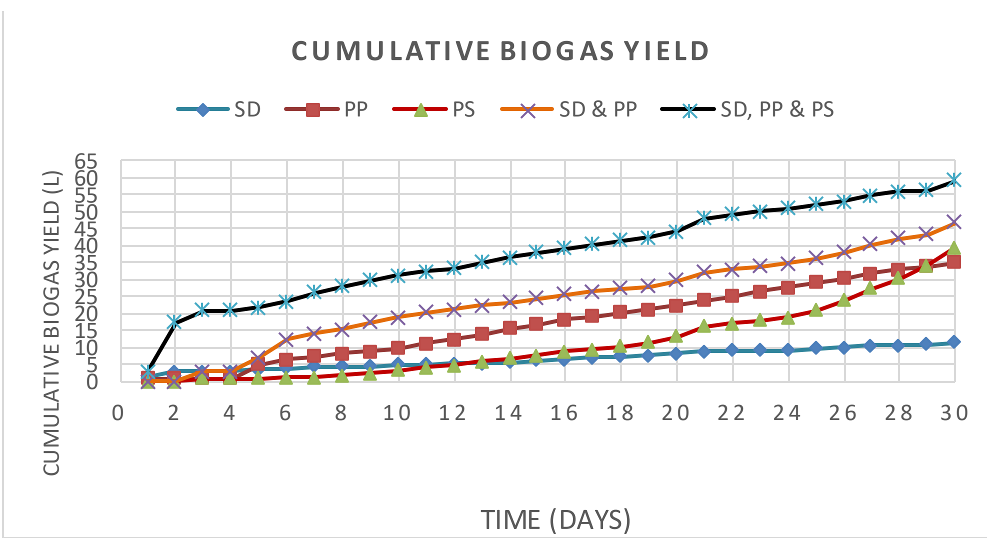

Fig.13: Graph of Cumulative biogas yield against Retention Time

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EFFECT OF C/N RATIO

C/N ratio is an important indicator for controlling biological systems. High C/N indicates rapid nitrogen consumption by methanogens and leads to lower gas production while low C/N ratio results in ammonia accumulation and an increase in pH values, which is toxic to methanogenic bacteria (Zhang et al., 2003). During anaerobic digestion, microorganisms utilize carbon 25 to 30 times faster than nitrogen (Yadvika et al., 2004). To meet these requirements, microbes need 20 to 30:1 ratio of C to N. From the results of the analysis done on the samples, the table below is derived

Carbon is required in any anaerobic digestion for building the cell structure of the methanogenic bacteria. From the table 1, it can be seen that the C/N ratio of the co-digested samples was not increased. This can be attributed to the synergy between the co-digested wastes. From table 1, the C/N ratio of sample PP and PS; 23.3 and 30.1 were seen to be within the range of the optimum C/N ratio, this can account for the early gas production and flammability in the PP. Late flammability presumes ammonia production due to low C/N ratio might be predominant at early digestion, this was seen in the blend of SD & PP. This delay period was also obtained by Ofoefule and Uzodimma (2009) in the blend of cassava peels waste with pig dung during anaerobic digestion process. Low C/N ratio as seen in the sample SD; 8.5 could be said to be low, leading to ammonia accumulation which caused an increased lag-time due to decreased activities of the methanogens.

EFFECT OF TOTAL SOLIDS AND VOLATILE SOLIDS

Total solid shows the total solid matter constituent of the entire organic waste both degradable and non-degradable. Volatile solid is the total amount of the wastes convertible to gaseous element and providing nutrients to the microorganisms for their function (biodigestion). Total and volatile solids content were characterized on the basis of which it was observed that a waste with high fibre content such as swine dung possesses lower nitrogen and energy contents, respectively (Table 1). Higher ash content also corresponded with higher volatile solids content as can be seen from the same table.

The total solids and volatile solids content of the various samples were decreasing over time, this and other parameters can be said to account for the low level of gas production. The low value of VS in sample SD led to its low biogas production since the microbes could not breakdown the substrates easily.

TEMPERATURE EFFECT

Two distinct temperature ranges for anaerobic digestion have been noted as the optimum digestion temperature: 35–55°C (mesophilic range) and 55 °C and above (thermophilic range). The ambient temperature for all the samples was always lower than the slurry temperature. The ambient temperature was affected by the natural weather condition, this was during the harmattan period (January - February), when it was usually cold at the early hours of the day and hot during the day. From figures 7 and 8, the ambient temperature was between the range of 28^0C - 39.5^0C while the slurry temperature was between the range of 28^0C - 44.5^0C for SD, 29.5^0C - 44^0C for PP, 28^0C - 44.5^0C for PS, 29^0C - 43.5^0C for SD & PP, 28^0C - 45^0C for SD, PP & PS. Amongst other determining parameters sample SD, PP & PS with the highest slurry temperature also had the highest cumulative biogas yield. Thus, it was carried out under the most favourable temperature range of 28-39.5ºC (mesophilic condition) which is meant for optimum anaerobic waste stabilization and of course increased biogas yield.

EFFECT OF pH VARIATION

The microorganisms that convert waste to biogas are sensitive to pH. It is generally agreed that at the initial stages of the overall process of biogas production, acid forming bacteria produce Volatile Fatty Acids (VFA) resulting in declining pH and diminishing growth of methanogenic bacteria and methanogenes (Vicenta*et al*., 1984; Cuzin*et al*., 1992).

That is, a low pH value inactivated microorganisms responsible for biogas production. The sample PP showed the highest acidity throughout the retention time with a range of 4.4 to 6.4. This can be said to account for the low level of methane production in that it flamed early and stopped after some days, it could also mean that the number of acidogens was by far greater than that of the methanogens. From figure 9, sample PS showed a continuous decrease in its pH level from 6.6 at charging to 5.5 after some days, this may be due to high VS in the mixture which was converted more intensely into VFA and other acidic metabolites by the activities of aerobes and facultative aerobes that were subsequently metabolized by methanogenic bacteria to generate biome thane (Dennis & Burke, 2001; Iyagba et al, 2009).

It was also observed that each of the samples had an increase in pH on the 28^{th} day, this can be said to be the reason for the increase in volume of biogas produced. Sample SD & PP was an improvement for the PP sample as

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the synergy improved the pH of the sample from the range of 4.4 – 6.4 to the range of 5.0 - 6.7. Sample E also showed improvement on the pH range from 5.0 – 7.0, considering the pH of SD, PP and PS which were 6.7, 4.8 and 6.6 respectively.

EFFECT OF TOTAL VIABLE COUNT

The results (from figure 11) showed SD had the highest level ($58.33X10^5$cfu/ml) and PS had the least ($33.33X10^5$cfu/ml) microbial loads at charging, but there was an appreciable increase of $48.33X10^6$cfu/ml and $15.83X10^6$cfu/ml respectively after 14 days of anaerobic digestion. However, after 30 days there was a subsequent decrease ($63.33X10^5$cfu/ml and $36.67X10^5$cfu/ml) in the microbial load. This indicates the fact that SD had more microbes and PS had the least from onset say due to the type of food swine feeds on.

100%PS had the least amount of TVC at charging, this can be said to be responsible for the delay in biogas production and a lag time of 26 days. The increase in microbial load was as result of conducive environment and availability of nutrients needed by microorganisms for growth, it also accounted for the increased biogas and bio-methane production after some days. In addition, the subsequent decrease showedthat the microbial load started depleting towards the 30th day. In view of the fact that anaerobic digestion of substrates is generally a function of time, whereas biogas production is highly dependent on microbial load, the analysis indicated that gas yield can be predicted as a function of time and total viable count (TVC).

BIOGAS YIELD AND FLAMMABILITY

From figures 9, 12, 13, table 2, generally, the low volume of biogas in the biodigestion of SD can be said to be due to the high concentrations of NH_4-N which inhibits the process of degradation of organic matter, causing a decrease in the volume of biogas produced (Oparaku et al, 2013). Whereas the low biogas production of sample PS can be attributed to the existence of lignin in lignocelluloses which creates a protective barrier that stops plant cell destruction by fungi and bacteria for conversion to biogas unless pre-treated (Angelidaki&Ellegaard, 2003) or due to the accumulation of VFAs which can result in partial inhibition in the biodigesters. When the VFAs were consumed, the partial inhibition was overcome and biogas production started. As a result of this there was a steady decrease in the pH level, then a subsequent increase resulting in production of flammable biogas.

This increase was due to conversion of VFA produced to methane by methanogens. For sample PP, there was an upsurge in the activities of the acidogens once more, which resulted in decrease in pH and reduced flammable biogas. Flammability is an evidence of about more than 45% methane content of any anaerobic digestion. However, co-digestion of the three samples had the same reaction as that of sample B but it continued flaming from the 2nd day to the 30th day, this indicates that the mixture increased the percentage methane content consistently which caused it to continue flaming despite its seeming acidic nature.

V. CONCLUSION

This study has shown that the wastes such as plantain peel, swine dung and pumpkin stalk which has been termed a nuisance to the environment can be utilized to produce biogas which can be used as an alternative to the widely known and used fossil fuel. The digestate after biogas has been produced can also be used to as fertilizer to improve plant growth and enhance soil capability in producing.

From the results, it can be seen that swine dung and plantain peel are not excellent in producing flammable biogas; capable of being utilized for any purpose such as cooking. This showed that in an event when plantain peel had to be digested alone, it should be pre-treated by the addition of inoculums or other treatment methods such as neutralizers to bring the pH to neutrality. Also, swine dung can be improved by proper grinding of particles for a dry collection and adequate dilution with water. Pumpkin stalk was seen to have a very long flammability lag time, although it showed evidence of producing flammable gas when flaming commenced. The study showed that the combination of swine dung and plantain peel improved the production of biogas tremendously when compared to their individual capability but it did not necessarily improve the methane production.

Looking at the mixture that comprised of swine dung, plantain peel and pumpkin stalk, it can be seen that there was improvement in both the volume of biogas produced and the time taken for it to flame. Therefore, it can be concluded that the co-digestion of the three wastes resulted in improved biogas production.

This study has shown a new source for wealth creation and at the same time a means of decontaminating the environment by waste recycling and transformation. This wastes that are consumed in large quantities in homes can be used to produce biogas, this will help them lose the name attached to them as being nuisance to the environment.

VI. RECOMMENDATIONS

The following has been recommended as a result of findings from this work:

- The gas produced should be further purified to enhance its scope of utilization such as in welding and automobiles.
- A method of gas collection which is safe and highly reliable should be enhanced.
- Highly advanced technological equipment should be constructed for the storing the gas separately from the digesters.
- Equipment that can purify and utilize the biogas that has been produced can be fabricated; this will encourage people to use biogas.
- Researches should be carried out to discover means of improving the methane quality produced and also the quality of the bio-fertilizer left after digestion.

REFERENCES

[1] Angelidaki, I&Ellegaard, L 2003, 'Codigestion of manure and organic wastes in centralized biogas plants.Status and future trends' *Applied Biochemistry and Biotechnology*, vol 109, pp. 95-105.

[2] Angelidaki, I. &Ahring, B. K. (2000). Methods for increasing the biogas potential from the recalcitrant organic matter contained in manure. Wat. Sci. Tech., 41(3), 189-194.

[3] Association of Official Analysis of Chemist (A.O.A.C.), (2005).Standard Official Methods of Analysis.15th ed., Washington D.C.

[4] Cuzin, N., Farinet, J. L., Segretain C., Labat, M. (1992).Methanogenic fermentation of cassava peel using a pilot plug flow digester. Bioresource Technol. 41: 259-264.

[5] Ezekoye, V. A. (2013). A comparative study of biogas production using plantain/almond leaves and pig dung, and its applications. International Journal of Physical Sciences.8(23):1291-1297.

[6] Fulford D. (1998) *Running a biogas programme.A handbook. "How biogas works."* Intermediate Technology Publication. 103-05 South Crampton Row, London. WC IB41 +, UK.Pp 33-34.

[7] Iyagba, E. I., Mangibo, I. A., & Mohammad, Y. S. (2009).The study of cow dung as co-substrate with rice husk in biogas production.*Scientific Research Essays*, 4 (9), 861-868.

[8] Meynell, P. J. (1982). Methane: Planning a Digester. Prism Press, Stable Court, Chatmington, Dovest.

[9] Nwankwo, J. I. (2014). Production of Biogas from Plantain Peels and Swine Droppings.IOSR Journal of Pharmacy and Biological Sciences. 9: 50-60.

[10] Ochei, J. and Kolhatkar A., (2008), Medical Laboratory Science, Theory and Practices, Tata McGraw-Hill, Page 311-347.

[11] Ofili I., Ibrahim A. H., Orban M. O., Abur F. F., Okpanachi A. I. (2010). Comparison of Biogas Yield from Anaerobic Digestion of Rabbit Waste and Swine Dung.International Journal of Advanced Engineering Research and Science (IJAERS). Vol-2: 10. 2349-6495

[12] Ofoefule, A. U., Uzodinma, E. O &Onukwuli, O. D. (2009).Comparative study of effect of different pretreatment methods on biogas yield from water hyacinth (*Eichorrniacrassipes)* Int J. Phy.Sci, 4(8): 535-539.

[13] Schumacher, Brian A. (2002) "Methods For The Determination Of Total Organic Carbon (Toc) In Soils And Sediments".

[14] Vicenta M., Pacheco G., Alamis M. L. A., Anglo P. G., Tan B. V., Silverio C. M. (1984). A study of some factors affecting biogas production from pineapple peelings. In: Bidin R, Chong CN, Wang CW (Eds.).Proceedings of the second ASEAN Workshop on biogas production applied to the management and utilization of food waste materials. Kaulaerengganu, Malaysia. Pp. 189 -202.

[15] Yadvika, S., Sreekrishnan, T. A., Konli, S. & Rena, V. (2004). Enhancement of biogas production from solid substrates using different techniques: A review. Bioresource Technology, 95:1-10.

[16] Zhang B., Zhang L. L., Zhang S. C., Shi H. Z., Cai W. M., (2003). The influence of pH onhydrolysis and acidogenesis of kitchen wastes in two-phase anaerobic digestion. Environmental Technology 26(3), 329-339.